View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Diposit Digital de Documents de la UAB

Universitat Autònoma de Barcelona

Dipòsit digital de documents de la UAB

This is the **accepted version** of the article:

Cramer, Wolfgang; Guiot, Joël; Fader, Marianella; [et al.]. Climate change and inter-connected risks to sustainable development in the Mediterranean. DOI 10.1038/s41558-018-0299-2

This version is avaible at https://ddd.uab.cat/record/203562

under the terms of the Free Access license

Environmental change represents multiple risks for sustainable development in the Mediterranean Basin

Revised Review Article for resubmission to Nature Climate Change

Wolfgang Cramer[1], Joël Guiot[2], Marianela Fader[3], Joaquim Garrabou[4,5], Jean-Pierre Gattuso[6,7], Ana Iglesias[8], Manfred A. Lange[9], Piero Lionello[10,11], Maria Carmen Llasat[12], Shlomit Paz[13], Josep Peñuelas[14,15], Maria Snoussi[16], Andrea Toreti[17], Michael Tsimplis[18] and Elena Xoplaki[19]

In the Mediterranean Basin, recent accelerated changes in the environment (climate, land use, pollution, biodiversity loss) have caused loss of life and damages to infrastructure and ecosystems. The future presents unprecedented risks for human well-being, socio-economic development, ecosystems and biodiversity. Policies for sustainable development need to aim for the mitigation of these risks but lack adequate information about the rates of environmental change and the combined risk they present to human society. For five interconnected impact domains (water, ecosystems, food, health and security), trends and scenarios point to significant risks during coming decades. More observations and better impact models exist for the Northern Mediterranean shores than for the South. This important bias is exacerbated by the large difference in financial resources available for adaptation and the development of resilience between north and south. A dedicated effort to synthesize existing scientific knowledge from all relevant disciplines is now underway to provide better understanding of the risks posed.

In the Mediterranean Basin, human society and the natural environment have co-evolved over several millennia with significant climatic variations, laying the ground for diverse and culturally rich communities. The region lies in a transition zone between mid-latitude and sub-tropical circulation regimes. It is characterized by a complex morphology of mountain chains and strong land-sea contrasts, dense and growing human population and various environmental pressures. Observed rates of climate change in the Mediterranean Basin exceed global trends for most variables. Annual mean temperatures are now 1.4 °C above late nineteenth century levels (Figure 1), notably during the summer months. Heat waves occur more frequently, and the frequency and intensity of droughts have increased since 1950.[1,2,3] For each of the most recent decades, the surface of the Mediterranean Sea has warmed by around 0.4 °C.[4] During the period 1945-2000, sea-level has risen at a rate of 0.7 ± 0.2 mm yr^{-1},[5] accelerating to 1.1 mm yr^{-1} for the period 1970-2006.[6] During the last two decades, sea-level has been estimated to rise by about 3 cm decade^{-1},[7] in part due to

[1]Mediterranean Institute for Biodiversity and Ecology (IMBE), Aix Marseille University, CNRS, IRD, Avignon University, Aix-en-Provence, France, [2]Aix Marseille University, CNRS, IRD, College de France, CEREGE, ECCOREV, Aix-en-Provence, France, [3]International Centre for Water Resources and Global Change (UNESCO), Federal Institute of Hydrology, Koblenz, Germany, [4]Institut Ciències del Mar (ICM-CSIC), Barcelona, Spain, [5]Mediterranean Institute of Oceanography (MIO) Aix Marseille University, CNRS, IRD, Toulon University de Toulon, Campus de Luminy-Oceanomed, Marseille, France, [6]Sorbonne Universités, UPMC Université Paris 06, CNRS-INSU, Laboratoire d'Océanographie de Villefranche, Villefranche-sur-mer, France, [7]Institute for Sustainable Development and International Relations, Sciences Po, Paris, France, [8]Department of Agricultural Economics, Universidad Politécnica de Madrid (UPM), Madrid, Spain, [9]Energy, Environment and Water Research Center, Cyprus Institute, Nicosia, Cyprus, [10]DiSTeBA (Department of Biological and Environmental Sciences and Technologies), University of Salento, Lecce, Italy, [11]CMCC (Euro-Mediterranean Centre on Climate Change), Italy, [12]Department of Applied Physics, University of Barcelona, Spain, [13]Department of Geography and Environmental Studies, University of Haifa, Haifa, Israel, [14]Consejo Superior de Investigaciones Científicas (CSIC), Global Ecology Unit, CREAF-CSIC-UAB, Bellaterra, Barcelona, Spain, [15]CREAF, Cerdanyola del Vallès, Barcelona, Spain, [16]Université Mohammed V de Rabat, Rabat, Morocco, [17]European Commission, Joint Research Centre, Ispra, Italy, [18]School of Ocean and Earth Sciences, , University of Southampton, UK, [19]Climatology, Climate Dynamics and Climate Change, Department of Geography, Justus-Liebig Universität Gießen, Germany

decadal NAO-related oscillations. Mediterranean sea water acidification is currently estimated to be −0.018 to -0.0028 pH units decade^{-1}.[8,9]

<insert Figure 1 about here>

Future warming in the Mediterranean region is expected to exceed global rates by 25 %, notably with summer warming at a pace 40 % larger than the global mean. Even for a "Paris-compliant" global warming of 1.5 °C, a 2.2 °C increase in regional daytime maxima is likely.[10] This increase is expected to lead to more frequent high temperature events and heat waves.[11] In the eastern Mediterranean, heat wave return periods may change from once every 2 years to multiple occurrences per year.[12] In the absence of strong global mitigation policies, the Mediterranean Sea may, by 2100, have warmed by more than 3 °C. A global temperature increase of 2°C would come with robust reduction in summer precipitation of e.g. ~10-15% in Southern France, Northwestern Spain and the Balkans as well as up to 30% reduction in Turkey and Portugal[13]. Scenarios with 2-4°C temperature increases in the 2080s for Southern Europe would imply widespread decreases in precipitation of up to 30% (especially in spring and summer months) and a switch to a lack of a frost season in the Balkans[14]. For each degree of global warming, mean rainfall will likely decrease by approx. 4% in much of the region (Figure 2), particularly in the south,[15] lengthening dry spells by 7 % already at 1.5 °C warming.[16] Heavy rainfall events are likely to intensify by 10-20 %, in all seasons except summer.[17]

<insert Figure 2 about here>

Projections of sea-level change for the Mediterranean coasts are complex due two factors. The regional response to changes in river runoff and salinity and the highly active tectonic movements of the coast in its Eastern parts cause significant spatial variability in sea level trends along the coasts. Global trends, estimated by the IPCC AR5 to be between 52 and 98 cm above present levels by 2100,[18] and between 75 and 190 cm by a semi-empirical model[19] will largely influence the Mediterranean Sea through the transport of water through the Strait of Gibraltar,[20] although the precise contribution is still uncertain. Recent studies of Antarctic ice-sheet dynamics indicate that process-based models may have to be adjusted upwards by about one meter for 2100.[21] Globally, CO_2 uptake by the oceans is expected to lead, by 2100, to a reduction between 0.15 and 0.41 pH units below 1870-1899 levels[22] – similar rates must be expected for the Mediterranean.[9,23]

Climate change impacts on people, infrastructure and ecosystems occur in combination with other trends of environmental change. The population of MENA (Middle East and North Africa) countries has quadrupled between 1960 and 2015, and the degree of urbanization has risen from 35 to 64 % during the same period,[24] trends are similar in other parts of the basin. Agricultural land management is intensifying, notably through enhanced irrigation; since many southern and eastern land systems appear to have potential for further increase in yields, agricultural management is likely to change further,[25] with consequences for water resources, biodiversity and landscape functioning. Air and water pollution, despite local improvements from wastewater treatment, increase as a consequence of growing urbanization, transport and other factors. Political conflicts impact the environment dramatically and migration pressure continues, affecting resource-poor economies and reducing the capacity to adapt to environmental change.

The combined risks arising from these forcings can be grouped in five major interconnected domains: water resources, ecosystems, food security, health and human security. Impacts and expected risks differ for each of them. However it is the risk posed by their combination which demands additional attention. Due to the limitations in resources the vulnerability to combined risks is unlikely to be a sum of the vulnerability to each separate risk. Their combination may exacerbate the magnitude of the combined impact or may produce successive more frequent stress periods which the least resilient countries will find difficult to cope with.

FIVE INTERCONNECTED IMPACT DOMAINS

Water resources are unevenly distributed among Mediterranean countries and are critically limited in the Southern and Eastern part of the basin (Figure 3). Mediterranean societies will face in the future the double challenge of meeting higher water demands from all sectors with less available freshwater water resources. Due to climate change (enhanced evapotranspiration and reduced rainfall) alone, water availability is likely to decrease substantially (by 2 to 15 % for a 2 °C warming), among the largest decreases in the world,[26] with significant increases in the length of meteorological dry spells[16,27] and droughts.[28] River flow is generally reduced, particularly in the South and the East where water is in critically short supply.[14] The median reduction in runoff almost doubles from about 9 % (likely range: 4.5–15.5 %) at 1.5 °C to 17 % (8–28 %) at 2 °C.[16] Water levels in lakes and reservoirs will likely decline. For example, the largest Mediterranean lake, the lake Beyşehir in Turkey, may dry out by the 2040s if its outflow regime is not adapted.[29] The seasonality of stream flows is very likely to change, with earlier declines of high flows from snow melt in spring, intensification of low flows in summer and greater and more irregular discharges in winter.[30] The currently critically low water availabilities per capita in Southeastern Spain and the Southern shores (Fig. 3) may further drop to below 500 m^3 cap^{-1} yr^{-1} in future, and in Greece and Turkey they may fall for the first time below 1000 m^3 cap^{-1} yr^{-1} in 2030 (the threshold generally accepted for severe water stress).[31] The importance of covering environmental flow requirements for assuring the healthy functioning of aquatic ecosystems will call for maintaining certain amounts of water in the systems, further limiting availability for human uses.[32] Further challenges to water availability and quality will likely arise from salt water intrusion caused by sea level rise and increasing water pollution on the Southern and Eastern shores,[31] from new industries, urban sprawl, tourism development and population growth. Recharge of groundwater will be diminished, affecting most of the region. The North-Western Sahara aquifer system has a renewal rate of only 40 % of the withdrawals,[33] indicating high vulnerability of the oasis systems that depend on it.

<insert Figure 3 about here>

The general increase in water scarcity as a consequence of climate change is enhanced by the increasing demand for irrigated agriculture to stabilize the production and to maintain food security. Irrigation water requirements in the Mediterranean region are projected to increase between 4 and 18% by the end of the century due to climate change alone (for 2°C and 5°C warming, respectively). Population growth may increase these numbers to between 22 and 74%.[34] Water demand for manufacturing is also projected to increase between 50 and 100% until the 2050s in the Balkans and Southern France.[14] The currently critically low water availabilities per capita in SE Spain and the Southern shores (Fig. 3) may further drop to below 500 m^3 cap^{-1} yr^{-1} in the future.[31] Satisfying water needs for human use is a challenge not only because of increasing scarcity, but also because water quality is under threat from pollution,[35] overexploitation and, in coastal areas, salt water intrusion caused by sea level rise. The expected increase in population, particularly in the coastal areas of eastern and southern Mediterranean countries, and the increasing urbanization not only lead to higher water demand, but also to further deterioration of water quality. Satisfying the demands for high quality drinking water, and for increasing irrigation demands is a complex problem, often involving conflicts between users of groundwater and land owners, or between countries. Flood risk, associated with extreme rainfall events, increase due to climate change, but also due to non-climatic factors such as increasingly sealed surfaces in urban areas and ill-conceived storm water management systems.

Natural and managed ecosystems (forests, wetlands, coastal and marine ecosystems) in the Mediterranean Basin are all adapted to conditions of the past centuries and therefore will be affected by mean changes in temperature and precipitation.[36] The increase in aridity, mainly by decreases in precipitation but also by higher temperatures, is likely the main threat to the diversity and survival of Mediterranean land ecosystems.[37,38] Additionally, higher fire risk, longer fire seasons, and more frequent large, severe fires are expected as a result of increasing heat waves in combination with drought and land use change.[39,40,41] Falling water levels and reduced water quality are also impacting wildlife in Mediterranean inland wetlands[42] and freshwater ecosystems.[26,32,43] The combination of these impacts with other global change drivers such as land use change (urbanization, agricultural abandonment or intensification), biological invasions, pollution and overexploitation, alters the structure and function of organisms, populations, communities and terrestrial ecosystems in the region, often towards drier and less productive systems.[39,44,45,46] Interactions between different drivers are complex, however the net outcome of most changes is a decrease of the capacity of many ecosystems to supply services at current levels.[47,48]

Climate change is severely modifying the structure and function of marine and coastal ecosystems. In marine ecosystems, higher sea temperatures are linked to increased mass mortality events of organisms and many different species.[49,50,51] Impacts on benthic population mortality were particularly strong and the geographical scale concerned tens to thousands of kilometers of coastlines.[49] The most dramatic events occurred during the summers of 1999 and 2003. Since 1999 almost every year mass mortality for some species has been reported, although in some years fewer species and more limited geographic ranges are affected.[50]

Shifts in the geographic distribution of a great diversity of native species (including fishes, crustaceans and echinoderms) have been linked to warming trends.[52,53,54,55] Warm-water species are moving northwards, colonizing and establishing permanent populations in new areas, in some cases within a few years. Meanwhile, in the northern oceanic areas warming is reducing suitable habitats for cold-water species, causing significant decrease in their abundance and even local population extinctions.[53,56,57] In addition the widening of the Suez canal and the transport of alien species through ballast water from ships worsens the situation. The wider consequences of the modification in species composition on the ecosystem functioning are still uncertain, however interspecific interactions (e.g. competition) are already causing changes in habitat use by former residents.[57]

More than 700 non-indigenous marine plant and animal species have been recorded so far in the Mediterranean,[58] many of them favored by the warmer conditions.[51,53] More than 50 % of these have entered through the Suez Canal. The Eastern Mediterranean is the area displaying the most severe environmental effects of invasive species.[59] During the coming decades, more tropical invasive species are expected to find suitable environmental conditions to colonize the entire Mediterranean spreading the ecological consequences already observed in some areas.[59]

Ocean acidification is expected to have a significant impact on a wide array of organisms producing carbonate shells and skeletons.[9,23] The effects encompass biological (e.g., early stage survival) as well as ecological (e.g. loss in biodiversity, changes biomass and trophic complexity) processes.[60] Effects of recent acidification in the Mediterranean Sea have led to a significant decrease in the coccolith thickness between 1993 and 2005.[8] Overall effects are highly species-dependent. At the community level, modifications in species composition and abundance shifting from assemblages dominated by calcifying species to non-carbonated species (e.g., erect macroalgae) were reported even under moderate decrease in pH.[61,62,63] In coming decades, synergies between warming and acidification are likely to affect large numbers of marine species including commercial species such as mussels.[64]

These ecological changes on land and in the ocean lead to an overall biodiversity loss. They may also compromise the numerous benefits and services Mediterranean ecosystems provide, including renewable natural resources (e.g., food, medicines, timber), environmental services (e.g., maintenance of biodiversity, soils and water, regulation of air quality and climate, carbon storage), and social services (e.g., opportunities for recreational, educational and leisure uses, traditional cultural values).[65,66]

Food production and security in the Mediterranean region are changing, due to social, economic and environmental changes.[67,68] While human population growth and increased affluence in some regions, along with changing diets will lead to higher demand for food products, plant, fish and livestock yields are projected to decline in many areas due to climatic and other stress factors. Despite ongoing adaptation through changed management, stronger droughts during the growing season increase the demand for irrigation.[69,70] Extreme events such as heat waves or heavy rainfall during critical phenological stages can also bring unexpected losses due to crop diseases, yield reduction and increased yield variability.[71,72] Yields for many summer and spring crops are expected to decrease due to climate change, especially in the South, for example by 2050 down to -40 % for legumes in Egypt, -12 % for sunflowers and -14 % for tuber crops in Southern Europe. Yield increases may also occur, due to crop-dependent CO_2-fertilization effects which increase water use efficiency and biomass productivity,[71] although the complex interactions among the various factors and current knowledge gaps imply high uncertainties.[73] Pests and diseases as well as mycotoxins could also represent a serious threat under unfavorable climate conditions.[74] Sea-level rise, combined with land subsidence, may significantly reduce locally the area available for agriculture. The effects of sea level rise will impose additional constraints to the agricultural land, especially in subsiding productive delta regions such as the Nile delta.[75]

Livestock production systems play a central role in climate change and agriculture due their productive, environmental and social functions.[76,77] The Mediterranean region is currently mainly characterized by mixed production system in the northern regions and in some southern ones, while grazing systems dominate the southern regions.[78] The number of agricultural holdings with grazing livestock (but associated with an increase of animals per farm) is in decline.[76] The abandonment of marginal land areas as well as social factors threaten the future of these pasture-based systems. Transition to mixed crop-livestock system could help in reducing climate adaptation costs and increase resilience to climate extremes in the Middle East and North Africa.[79] In these regions, livestock units have increased by 25 % from 1993 to 2013; however, the consumption growth has led to an animal food and feed import of around 32 % of the total food import in 2014.[80] The demand for livestock products is expected to grow in the next decades but there are significant challenges for livestock systems under changing climate and social conditions. The impacts of climate change on local production potential, combined with the growing demand of animal products due to population growth and changing consumption habits will increase the food dependence of the south Mediterranean countries in the coming decades (estimated at around 50 % for all food products in the Maghreb, ref *81*).

Fisheries landings have shifted significantly for nearly 60 % of the 59 most abundant commercial fish. Most (~70 %) declined (on average by 44 %) but increases were also found, mostly for species with short life spans, which seem to have benefited from increased temperature.[82] For six out of eight examined fish species, landings per unit of effort are correlated with temperature, indicating the influence effect on landings when the fishing effect is accounted.[82] 91% of assessed stocks of fish in the Mediterranean were being overfished in 2014.[83] While fish stocks are climate-sensitive and vulnerable, both climate change and overfishing undermine the future of Mediterranean fisheries.[84]

Fisheries and aquaculture, crucial for food security and the economy of the Mediterranean,[68] are currently impacted mostly by overfishing and coastal development.[85] Ocean warming and acidification will very likely impact fisheries more significantly during the coming decades, with more than 20 % of exploited fish and marine invertebrates expected to become locally extinct around 2050. Mediterranean countries import more fish products than they export, as a result of the increasing demand for seafood. Despite being major exporters, France, Spain and Italy are the countries with the highest trade deficits for seafood. By 2040–2059 more than 20 % of exploited fishes and invertebrates currently occurring in the eastern Mediterranean are projected to become locally extinct due to climate change.[86,87] By 2070–2099, 45 additional species are expected to qualify for the IUCN Red List whereas 14 more are expected to become extinct.[88] The expected migration of species to cooler areas as the ocean warms up[89] is ultimately limited in enclosed seas and the Mediterranean Sea has been described as a ‘cul-de-sac’ for endemic fishes, including commercial species, facing climate change.[88]

Overall, expected climate and socio-economic changes pose threats for food security in the Mediterranean region. These pressures will not be homogeneous across the region and the production sectors, creating further regional imbalances and disputes. Thus, trade will represent a key factor in maintaining food security. Sustainability of food production represents an issue in unfavorable climate and socio-economic conditions. Collaborative management of fisheries and oceanic food resources and sustainable management of the Mediterranean Sea will be increasingly more necessary as unsustainable practices in one country enhanced by climate change effects and land based pollution will affect catches in all other countries.

Climate change is one of many drivers affecting *human health*, acting directly (through heat, cold, drought, storms and other forcings) or indirectly (through changes in food provision and quality, air pollution or other aspects of the social and cultural environments). Impacts vary in scale and timing as a function of the local environmental conditions and the human population vulnerability.[90] In the Mediterranean region, hot spots of heat wave and ambient temperature changes exist along the coasts and in densely populated urban centers.[91] Heat-related illnesses and fatalities can occur when high ambient temperatures (in particular combined with high relative humidity) exceed the body's natural ability to dissipate heat. For example, recent analysis for Barcelona shown an increased risk in mortality due to natural, respiratory, and cardiovascular causes for hot nights with temperatures higher than 23 °C.[92] Older adults, young children and persons with pre-existing and chronic medical conditions are particularly susceptible to these illnesses and are at high risk for heat-related mortality.[93] Although most Mediterranean inhabitants are relatively acclimatized to high temperatures, an increase in the intensity and frequency of heat waves, or a shift in seasonality, are significant health risks for vulnerable population groups, including those who live in poverty with substandard housing and restricted access to air-conditioned areas.[94] The degree at which heat-related morbidity and mortality rates will increase in the next decades will depend on the adaptive capacity of the Mediterranean population groups through acclimatization, on the adaptation of the urban environment to reduce heat-island effects, on the implementation of public education programs and on health system preparedness.[90] Increased population life expectancy implies that the health protection of elderly people will become a major challenge for all Mediterranean countries under heat wave conditions. Indeed, increased mortality was found among people over 65 years in Athens at high and very high temperatures.[95] During the severe heat wave in France (summer 2003) most of the extra deaths occurred in the elderly population.[96]

Climate change may influence the emergence of vector-borne diseases since the life-cycle dynamics of the vector species, pathogenic organisms and the reservoir organisms are all sensitive to weather conditions.[97] The rates of replication, development, and transmission of the pathogens depend more strongly on temperature relative to other host-pathogen interactions.[98] In recent years, several outbreaks of different vector-borne diseases have been documented in the Mediterranean region. For some of them, such as the West Nile Virus, links with climatic change have been demonstrated.[99]

There is a high certainty that the recent observed climatic trends will contribute to the future transmission potential of vector / food / water-borne diseases in the region.[100] Predicting the consequences of climate change for infectious disease severity and distributions remains a challenge, particularly for vector-borne infections of humans which compounded by the complex interactions between hosts, pathogens and vectors or intermediate hosts, that make the cumulative influence of climate change on disease outcomes elusive.[98,101] For 2025 and 2050, areas with elevated probability for West Nile infections will likely expand and eventually include most of the Mediterranean countries.[102]

During recent years, dengue fever cases were reported in several Mediterranean countries, such as Croatia, France, Greece, Italy, Malta, Portugal and Spain. Although most cases were probably imported, in 2010 local transmission of dengue was reported in both Croatia and France. Today, there is an apparent threat of dengue outbreaks in the Mediterranean European countries.[103,104]

Human security is affected by both, impacts of extreme events and societal conflict, in other words, by a combination of natural and social processes[105]. Globally, there is a trend toward higher exposure to risk: between 1970 and 2010, global population grew by 87 %, but the population living in flood plains increased by 114 % and in cyclone-prone coastlines by 192 %.[106] In the Mediterranean, a third of the population (about 150 million people) lives close to the sea. A small tidal range and relatively limited storm surges have led to the development of coastal infrastructure, land use systems and human settlements that are very close to mean sea level.[107] Sea level rise, which may well exceed recent IPCC estimates and reach more than 1 m in 2100[19], will have considerable impact. High risk for wave overtopping in Northern Mediterranean ports is manifest,[108,109] however such coastal risks may be even higher along the Southern and Eastern shores, where adaptive capacity is generally limited by weaker economic and institutional conditions. Mediterranean port cities with more than 1 million inhabitants each are considered at increasing risk from severe storm-surge flooding, rising sea and local land subsidence.[110] By 2050, for the lower sea-level rise scenarios and current adaptation measures, half of the 20 world's cities with the highest increase of the average annual losses will be in the Mediterranean.[111] Coastal areas at extremely high risk are predominantly located in the southern and eastern Mediterranean region including Morocco, Algeria, Libya, Egypt, Palestine, and Syria,[112] most of which are presently subject to political instability and thus less able to deal with the additional environmental pressures (Figure 4).

<insert Figure 4 about here>

In Europe, up to an additional 1.6 million people each year would experience coastal flooding by 2080 under a business-as-usual scenario, unless additional adaptation measures are taken.[113] This number includes the northern Mediterranean, and northern and western Europe. In North African countries 1 m sea-level rise would impact approximately 41,500 km^2 of the territory and at least 37 million people (~11 %).[114] It is currently not possible to reconcile these estimates for a full Mediterranean assessment, but they indicate the order of magnitude of people impacted by coastal risks.

Coastal areas suffer from intrusion of saltwater and this will increase as sea level rises. In Egypt, about 30 % of the irrigated farmlands are affected by salt intrusion.[115] Of the Northern cultivated land and both Middle and Southern Delta regions, 60 % and 20 %, respectively, are considered salt-affected soils.[116] This environmental degradation pushes Egypt's increasing population into more and more concentrated areas.[117]

Away from the coast, additional risks are also associated with increasing wildfires caused by warming, drought and land abandonment. The combined climate and non-climate related forcings have the potential to induce large-scale human migration towards safer areas. Rapid onset events—such as floods or other natural disasters—are clearly linked to environmentally induced displacement and relocation. In contrast, for slower changes, the forcings are more indirect. Nonetheless, sea level rise and/or increased intensity of droughts and storms will over time trigger some form of permanent population migration at significant scales unless protective measures establishing an acceptable safety level are put in place.[118]

Droughts or changes in ecosystem service supply may also aggravate social conflict and may trigger forced migration. Efforts to mitigate one risk may reduce the resilience of human communities or accentuate other risks where resources are limited. Due to its cultural, geopolitical and economic complexity, the Mediterranean basin has historically been a region of social and political instability. The arrival of climate change impacts as additional stressor creates increased risks to human security in the region, makes the Mediterranean basin communities more vulnerable and hence increases human insecurity.[119] Besides anthropogenic climate change, mismanagement and overexploitation of natural resources during the past century have contributed to increased vulnerability. The main underlying reasons are: (i) the advanced depletion of natural resources both off and onshore, (ii) desertification that advances northward with decreasing water supplies and consequent food insecurity, particularly in the Middle East and North Africa (Figure 5), and (iii) the big gap in affluence between developed and more attractive European nations, and the much less developed Middle Eastern and North African neighbors with the colonial past underpinning mistrust and separation.[120,121]

<insert Figure 5 about here>

With several severe, unprecedented, and persistent droughts with subsequent income losses in the farming sector in Syria, the degree to which recent climate change has contributed to social conflicts and war is debated.[122] However a widely shared view is that while these droughts are unlikely to have been the direct cause of conflicts they could have significantly worsened human livelihoods in the region[1] and have thereby driven more people to migrate.

A PAN-MEDITERRANEAN INTEGRATED RISK ASSESSMENT IS NEEDED

IPCC AR5 has identified emergent risks from the interaction between impacts across sectors, as well as consequences of adaptation and mitigation actions at global scale.[123] The Mediterranean Basin provides a particularly strong regional case for such risks, as these may amplify each other or simply absorb significant resources by their successive occurrence. For example, direct impacts of climate change on agriculture, water supply and fisheries are amplified by the consequences of biodiversity loss on ecosystem services (pollinators, nutrient cycling, water purification). Several risks are also amplified by direct human action through inefficient management of water, land and marine resources. While health impacts arise to a large degree from exposure and vulnerability they are enhanced by climate change (extreme events, air pollution, emerging diseases). Urban and low-lying coastal areas are more at risk than other settled regions because of the direct impacts of sea-level rise, but also due to the infrastructural and socio-economic losses that make adaptation costs less affordable. Social and political instability can be major contributors to climate vulnerability, notably for impoverished population groups. Global teleconnections may also play a major role in the region, both in the climate system (Antarctic glacier destabilization leading to sea-level rise) and in the economic system, e.g. through food commodity market changes driven by crop failures and enhanced yield variability elsewhere, and also through climate refugees originating from non-Mediterranean regions such as sub-Saharan Africa. Governance options for collaborative adaptation and mitigation activities are limited by economic disparities, as well as by the existence of failing states, in the region.

At the global scale, “critical limits” and “safe operating spaces” are now estimated for multiple impact sectors.[124] However, despite considerable amounts of available information, it remains a challenge to quantify such critical limits for the Mediterranean, for a number of reasons. First, scaling of global trends to the regional level could underestimate impacts significantly because warming and drying occur faster in the Mediterranean region than at the global scale. Second, socio-economic and political instabilities are rising in several Mediterranean countries, reducing coordinated action, diminishing resilience and the capacity to adapt to environmental change. A comprehensive and coherent assessment of the combined risks has not been undertaken; yet it is urgently needed.

Substantial amounts of observations and scientific capacity for risk assessment exist around the Mediterranean, but resources are unevenly distributed and some of the most vulnerable regions and economic sectors are insufficiently studied. Decision makers therefore have insufficient access even to the existing knowledge. A reason for this may be the insufficient networking and exchange between experts caused by several factors including cultural, political and language barriers. To contribute to overcoming these barriers, to identify knowledge gaps and to provide unbiased information to policy makers, an international group of more than 390 scientists has now established a network, the Mediterranean Experts on Environmental and Climate Change (MedECC, http://www.medecc.org/). The group works in close contact with intergovernmental agencies, such as the Climate Experts Group of the Union for the Mediterranean and the Barcelona Convention. Based on voluntary contributions of time and content by its member scientists, the group maintains its independence in defining the topical agenda for its interdisciplinary and inter-sectoral assessment. Similar to international science-policy interfaces, such as the IPCC or the IPBES, a mechanism is now in place to provide an unbiased assessment, targeting clear needs expressed by policy makers, and aiming for a concluding process of communication of key conclusions.

References

1. Kelley, C.P. *et al*. Climate change in the Fertile Crescent and implication of the recent Syrian drought. *Proc. Natl. Acad. Sci. U.S.A.* **112**, 3241-3246 (2015).
2. Hartmann, D.L. *et al*. Observations: Atmosphere and Surface. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F. *et al*. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA (2013).
3. Vicente-Serrano, S.M. *et al*. Evidence of increasing drought severity caused by temperature rise in southern Europe. *Env. Res. Lett.* **9**, 044001 (2014).
4. Macias, D., Garcia-Gorriz, E. & Stips, A. Understanding the causes of recent warming in Mediterranean waters. How much could be attributed to climate change? *PLoS ONE* **8**(11), e81591 (2013).
5. Calafat, F.M. & Gomis, D. Reconstruction of Mediterranean sea level fields for the period 1945-2000. *Gl. Planet. Change* **66**(3-4), 225-234 (2009).
6. Meyssignac, B. *et al*. Two-dimensional reconstruction of the Mediterranean sea level over 1970–2006 from tide gage data and regional ocean circulation model outputs. *Gl. Planet. Change* **77**(1-2), 49-61 (2011).
7. Tsimplis, M.N. *et al*. The effect of the NAO on sea level and on mass changes in the Mediterranean Sea. *J. Geophys. Res. Oceans* **118**, 944–952 (2013).
8. Meier, K.J.S., Beaufort, L., Heussner, S. & Ziveri, P. The role of ocean acidification in *Emiliania huxleyi* coccolith thinning in the Mediterranean Sea. *Biogeosci.* **11**, 2857-2869 (2014).
9. Kapsenberg, L., Alliouane, S., Gazeau, F., Mousseau, L. & Gattuso, J.-P. Coastal ocean acidification and increasing total alkalinity in the northwestern Mediterranean Sea. *Ocean Sci.* **13***, 411-426* (2017).
10. Seneviratne, S.I., Donat, M.G., Pitman, A.J., Knutti, R. & Wilby, R.L. Allowable CO_2 emissions based on regional and impact-related climate targets. *Nature* **529**, 477-483 (2016).
11. Jacob, D. *et al*. EURO-CORDEX: new high-resolution climate change projections for European impact research. *Reg. Env. Change* **14**(2), 563-578 (2014).
12. Zittis, G., Hadjinicolaou, P., Fnais, M. & Lelieveld, J. Projected changes in heat wave characteristics in the eastern Mediterranean and the Middle East. *Reg. Env. Change* **16**(7), 1863–1876 (2015).
13. Vautard, R. *et al*. The European climate under a 2°C global warming. *Env. Res. Lett.* **9**(3), 034006 (2014).
14. Forzieri, G. *et al*. Ensemble projections of future streamflow droughts in Europe. *Hydrol. Earth Syst. Sci.* **18**, 85-108 (2014)
15. Lionello, P. & Scarascia, L. The relation between climate change in the Mediterranean region and global warming. *Reg. Environm. Change* (2018)
16. Schleussner, C.-F. *et al*. Differential climate impacts for policy-relevant limits to global warming: the case of 1.5 °C and 2 °C. *Earth Syst. Dyn.* **7**, 327-351 (2016).

17. Toreti, A. *et al*. Projections of global changes in precipitation extremes from Coupled Model Intercomparison Project Phase 5 models. *Geophys. Res. Lett.* **40**, 4887-4892 (2013).
18. Church, J.A. *et al*. Sea Level Change. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F. *et al*. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA (2013)
19. Vermeer, M. & Rahmstorf, S. Global sea level linked to global temperature. *Proc. Natl. Acad. Sci. U.S.A.* **106**(51), 21527-21532 (2009).
20. Jordà, G. & Gomis, D. On the interpretation of the steric and mass components of sea level variability: The case of the Mediterranean basin. *J. Geophys. Res. Oceans* **118**, 953-963 (2013).
21. DeConto, R.M. & Pollard, D. Contribution of Antarctica to past and future sea-level rise, *Nature* **531**, 591-597 (2016).
22. Magnan, A.K. *et al*. Implications of the Paris agreement for the ocean. *Nature Clim. Change* **6**, 732-735 (2016).
23. Palmiéri, J. *et al*. Simulated anthropogenic CO_2 storage and acidification of the Mediterranean Sea. *Biogeosci.* **12**, 781-802 (2015).
24. World Bank Group 2017, https://data.worldbank.org/region/middle-east-and-north-africa, accessed Sep 3, 2017
25. Mueller, N.D. *et al*. Closing yield gaps through nutrient and water management. *Nature* **490**, 254-257 (2012).
26. Jiménez Cisneros, B.E. *et al*. Freshwater resources. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B. *et al*. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 229-269 (2014).
27. Kovats, R.S. *et al*. Europe. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R. *et al*. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1267-1326 (2014)
28. Tsanis, I.K., Koutroulis, A.G., Daliakopoulos, I.N. & Jacob, D. Severe climate-induced water shortage and extremes in Crete. *Clim. Change* **106**(4), 667-677 (2011)
29. Bucak, T. *et al*. 2017 Future water availability in the largest freshwater Mediterranean lake is at great risk as evidenced from simulations with the SWAT model. *Sci. Total Environm.* **581-582**, 413-425 (2017).
30. García-Ruiz, J.M., López-Moreno, J.I., Vicente-Serrano, S.M., Lasanta–Martínez, T. & Beguería, S. 2011 Mediterranean water resources in a global change scenario. *Earth-Science Rev.* **105**(3-4), 121-139 (2011).
31. Ludwig, W., Bouwman, A.F., Dumont, F. & Lespinas, F. Water and nutrient fluxes from major Mediterranean and Black Sea rivers: Past and future trends and their implications for the basin-scale budgets. *Global Biogeochem. Cycl.* **24**(4), GB0A13 (2010.
32. Hermoso, V. & Clavero, M. Threatening processes and conservation management of endemic freshwater fish in the Mediterranean basin: a review. *Marine & Freshw. Res.* **62**(3), 244-254 (2011).
33. Gonçalvès, J., Petersen, J., Deschamps, P., Hamelin, B. & Baba-Sy, O. Quantifying the modern recharge of the “fossil” Sahara aquifers. *Geophys. Res. Lett.* **40**(11), 2673-2678 (2013).
34. Fader, M., Shi, S., Von Bloh, W., Bondeau, A. & Cramer, W. 2016 Mediterranean irrigation under climate change: more efficient irrigation needed to compensate increases in irrigation water requirements. *Hydrol. Earth Syst. Sci.* **20**, 953-973 (2016).
35. Bartrons, M. & Peñuelas, J. Pharmaceuticals and personal-care products in plants. *Trends Plant Sci.* **22**(3), 194-203 (2017).
36. Guiot, J. & Cramer, W. Climate change: The 2015 Paris Agreement thresholds and Mediterranean basin ecosystems. *Science* **354**, 465-468 (2016).

37. Gouveia, C.M., Trigo, R.M., Beguería, S. & Vicente-Serrano, S.M. Drought impacts on vegetation activity in the Mediterranean region: An assessment using remote sensing data and multi-scale drought indicators. *Gl. Planet. Change* **151**, 15-27 (2017).
38. Santonja *et al*. Plant litter mixture partly mitigates the negative effects of extended drought on soil communities and litter decomposition in a Mediterranean oak forest. *J. Ecol.* **105**(3), 801-815 (2017).
39. Duguy, B. *et al*. Effects of climate and extreme events on wildfire regime and their ecological impacts. In: Navarra, A. & Tubiana, L. (eds.) *Regional Assessment of Climate Change in the Mediterranean. Volume 2: Agriculture, Forests and Ecosystem Services and People*, Springer Publishers, pp. 101-134 (2013)
40. Turco, M., Llasat, M.C., von Hardenberg, J. & Provenzale, A. Climate change impacts on wildfires in a Mediterranean environment. *Clim. Change* **125**, 369–380 (2014).
41. Ruffault, J., Moron, V., Trigo, R.M. & Curt, T. Objective identification of multiple large fire climatologies: an application to a Mediterranean ecosystem. *Env. Res. Lett*. **11**, 7 (2016).
42. Zacharias, I. & Zamparas, M. Mediterranean temporary ponds. A disappearing ecosystem. *Biodiv. & Conserv.* **19**(14), 3827-3834 (2010).
43. Klausmeyer, K.R. & Shaw, M.R. Climate change, habitat loss, protected areas and the climate adaptation potential of species in Mediterranean ecosystems worldwide. *PLoS ONE* **4**(7), e6392 (2009).
44. Peñuelas, J. *et al*. Evidence of current impact of climate change on life: a walk from genes to the biosphere. *Gl. Change Biol.* **19**, 2303-2338 (2013).
45. Peñuelas, J. *et al*. 2017. Impacts of global change on Mediterranean forests and their services. *Forests* **8**(12), 463 (2017).
46. Williams, A.P. *et al*. Temperature as a potent driver of regional forest drought stress and tree mortality. *Nature Clim. Change* **3**, 292-297 (2013).
47. Doblas-Miranda, E. *et al*. A review of the combination among global change factors in forests, shrublands and pastures of the Mediterranean Region: Beyond drought effects. *Gl. Planet. Change* **148**, 42-54 (2017).
48. Garcia-Nieto, A.P. *et al*. Impacts of urbanization around Mediterranean cities: changes in ecosystem service supply. *Ecol. Ind.* 91, 589-606 (2018).
49. Garrabou, J. *et al*. Mass mortality in Northwestern Mediterranean rocky benthic communities: effects of the 2003 heat wave. *Gl. Change Biol.* **15**, 1090–1103 (2009).
50. Rivetti, I., Fraschetti, S., Lionello, P., Zambianchi, E. & Boero, F. Global warming and mass mortalities of benthic invertebrates in the Mediterranean Sea. *PLoS ONE* **9**(12), e115655 (2014).
51. Marbà, N., Jorda, G., Agustí, S., Girard, S.C. & Duarte, C.M. Footprints of climate change on Mediterranean Sea biota. *Frontiers Mar. Sci.*, 13 Aug 2015 (2015).
52. CIESM Climate warming and related changes in Mediterranean marine biota. *CIESM Workshop Monographs* **35** (Briand, F., ed.), 152 pp, Monaco (2008).
53. Azzurro, E., Moschella, P. & Maynou, F. Tracking signals of change in Mediterranean fish diversity based on local ecological knowledge. *PLoS ONE* **6**(9), e24885 (2011).
54. Lloret, J. *et al*. How a multidisciplinary approach involving ethnoecology, biology and fisheries can help explain the spatio-temporal changes in marine fish abundance resulting from climate change. *Gl. Ecol. & Biogeogr.* **24**, 448-461 (2015).
55. Parravicini, V. *et al*. Climate change and warm-water species at the northwestern boundary of the Mediterranean Sea. *Mar. Ecol. Evol. Persp.* **36**, 897-909 (2015).
56. Chevaldonné, P. & Lejeusne, C. Regional warming-induced species shift in north-west Mediterranean marine caves. *Ecol. Lett.* **6**(4), 371–379 (2003).
57. Milazzo, M. *et al*. Warming-related shifts in the distribution of two competing coastal wrasses. *Mar. Environm. Res.* **120**, 55-67 (2016).
58. Galil, B.S., Marchini, A. & Occhipinti-Ambrogi, A. East is east and West is west? Management of marine bioinvasions in the Mediterranean Sea. *Est. Coast. Shelf Sci.* **201**, 7-16 (2018).

59. Vergés, A. *et al*. Tropical rabbitfish and the deforestation of a warming temperate sea. *J. Ecol.* **102**, 1518–1527 (2014).
60. Gattuso, J.-P. *et al*. Contrasting future for ocean and society from different anthropogenic CO_2 emissions scenarios. *Science* **349**(6243) (2015).
61. Hall-Spencer, J.M. *et al*. Volcanic carbon dioxide vents show ecosystem effects of ocean acidification. *Nature* **454**, 96-99 (2008).
62. Kroeker, K.J., Micheli, F., Gambi, M.C. & Martz, T.R. Divergent ecosystem responses within a benthic marine community to ocean acidification. *Proc. Natl. Acad. Sci. U.S.A.* **108**, 14515-14520 (2011).
63. Linares, C. *et al*. Persistent acidification drives major distribution shifts in marine benthic ecosystems. *Proc. Royal Soc. Ser. B* **282**(1818) (2015).
64. Rodrigues, L.C. *et al*. Sensitivity of Mediterranean bivalve mollusc aquaculture to climate change, ocean acidification, and other environmental pressures: Findings from a producer survey. *J. Shellfish Res.* **34**, 1161-1176 (2015).
65. Liquete, C., Piroddi, C., Macias, D., Druon, J.-N. & Zulian, G. Ecosystem services sustainability in the Mediterranean Sea: assessment of status and trends using multiple modelling approaches. *Sci. Rep.* **6**, 34162 (2016).
66. Martín-López, B. *et al*. Ecosystem services supplied by Mediterranean Basin ecosystems. In: Potschin, M., Haines-Young, R., Fish, R., Turner, R.K. (eds) *Routledge Handbook of Ecosystem Services*. Routledge, London and New York, pp. 405-414 (2016)
67. Paciello, M.C. (ed.), Building sustainable agriculture for food security in the Euro-Mediterranean area: Challenges and policy options, IAI, Rome, OCP, Rabat, 334pp. (2015)
68. Piante, C. & Ody, D. Blue growth in the Mediterranean Sea: the challenge of good environmental status. MedTrends Project, WWF-France, 192pp. (2015)
69. Albiac, J., Esteban, E., Tapia, J. & Rivas, E. Water scarcity and droughts in Spain: Impacts and policy measures. In: Schwabe, K., Albiac-Murillo, J., Connor, J.D., Hassan, R. & Meza González, L. (eds.) *Drought in Arid and Semi-Arid Regions: A Multi-Disciplinary and Cross-Country Perspective*. Springer (2013)
70. Iglesias, A., Garrote, L., Quiroga, S. & Moneo, M. From climate change impacts to the development of adaptation strategies: challenges for agriculture in Europe. *Clim. Change* **112**, 143–168 (2012).
71. Deryng, D. *et al*. Regional disparities in the beneficial effects of rising CO_2 concentrations on crop water productivity. *Nature Clim. Change* **6**, 786-790 (2016).
72. Giannakopoulos, C. *et al*. Climatic changes and associated impacts in the Mediterranean resulting from a 2 °C global warming. *Gl. Planet. Change* **68**(3), 209-224 (2009).
73. Fitzgerald, G.J. *et al*. Elevated atmospheric [CO_2] can dramatically increase wheat yields in semi-arid environments and buffer against heat waves. *Gl. Change Biol.* **22**, 2269–2284 (2016).
74. Miraglia, M. et al. Climate change and food safety: An emerging issue with special focus on Europe. *Food & Chem. Toxicol.* **47**, 1009–1021 (2009).
75. Link, P.M., Kominek, J. & Scheffran, J. Impacts of sea level rise on the coastal zones of Egypt. *Mainzer Geographische Studien* **55**, 79-94, Working paper CLISEC-25 (2012).
76. Bernués, A., Ruiz, R., Olaizola, A., Villalba, D. & Casasus, I. Sustainability of pasture-based livestock farming systems in the European Mediterranean context: Synergies and trade-offs. *Livestock Science* **139**(1-2), 44-57 (2011).
77. Herrero, M. & Thornton, P.K. Livestock and global change: Emerging issues for sustainable food systems. *Proc. Natl. Acad. Sci. U.S.A.* **110**, 20878-20881 (2013).
78. Herrero, M. *et al*. Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proc. Natl. Acad. Sci. U.S.A.* **110**, 20888-20893 (2013).
79. Weindl, I. *et al*. Livestock in a changing climate: production system transitions as an adaptation strategy for agriculture. *Env. Res. Lett.* **10**, 094021 (2015).

80. UN Food and Agriculture Organization (FAO) Livestock contribution to food security in the Near East and North Africa. FAO regional conference for the Near East, 33th Session, Beirut, Lebanon, 18-22 April 2016 (2016).
81. INRA/Pluriagri Addressing agricultural import dependence in the Middle East-North Africa region through the year 2050 (2015).
82. Tzanatos, E., Raitsos, D.E., Triantafyllou, G., Somarakis, S. & Tsonis, A.A. Indications of a climate effect on Mediterranean fisheries. *Clim. Change* **122**, 41-54 (2014).
83. EC (2014) European Commission. Maritime Affairs and Fisheries. On the state of fish stocks. https://ec.europa.eu/dgs/maritimeaffairs_fisheries/magazine/en/policy/state-fish-stocks (last visited May 2018).
84. Coll, M. *et al*. 2012 The Mediterranean Sea und siege: spatial overlap between marine biodiversity, cumulative threats and marine reserves. *Global Ecol. Biogeogr*. **21**(4), 465-480 (2012).
85. European Commission (EC) Communication from the Commission to the European Parliament and the Council concerning a consultation on fishing opportunities for 2015 under the Common Fisheries Policy, COM (2014).
86. Jones, M.C. & Cheung, W.W.L. Multi-model ensemble projections of climate change effects on global marine biodiversity. *ICES J. Mar. Sci.* **72**, 741-752 (2015).
87. Cheung, W.W.L. *et al*. Structural uncertainty in projecting global fisheries catches under climate change. *Ecol. Model.* **325**, 57-66 (2016).
88. Ben Rais Lasram, F. *et al*. The Mediterranean Sea as a 'cul-de-sac' for endemic fishes facing climate change. *Gl. Change Biol.* **16**, 3233-3245 (2010).
89. Poloczanska, E.S. *et al*. Responses of marine organisms to climate change across oceans. *Frontiers Mar. Sci.* **3**, 62 (2016).
90. Smith, K.R. *et al*. Human health: impacts, adaptation, and co-benefits. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B. *et al*. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 709-754, (2014).
91. Kuglitsch, F.G. *et al*. Heat wave changes in the eastern Mediterranean since 1960. *Geophys. Res. Lett.* **37**(4) (2010).
92. Royé, D. The effects of hot nights on mortality in Barcelona. *Int. J. Biometeorol.* 61(12):2127-2140 (2017).
93. Centers for Disease Control and Prevention (CDC), Heat Stress. (2015) Available: http://www.cdc.gov/niosh/topics/heatstress
94. Paz, S., Negev, M., Clermont, A. & Green, M.S. Health aspects of climate change in cities with Mediterranean climate, and local adaptation plans. *Int. J. Environm. Res. Public Health* **13**(4), 438 (2016).
95. Paravantis, J., Santamouris, M., Cartalis, C., Efthymiou, C. & Kontoulis, N. Mortality associated with high ambient temperatures, heatwaves, and the urban heat island in Athens, Greece. *Sustainability* **9**(4), 606 (2017).
96. Fouillet, A. *et al*. Has the impact of heat waves on mortality changed in France since the European heat wave of summer 2003? A study of the 2006 heat wave. *Int. J. Epidemiol.* **37**(2), 309-317 (2008).
97. Parham, P.E. *et al*. Climate, environmental and socio-economic change: weighing up the balance in vector-borne disease transmission. *Phil. Trans. Royal Soc. London B: Biol. Sci.* **370**(1665), 20130551 (2015).
98. Altizer, S., Ostfeld, R.S., Johnson, P.T., Kutz, S. & Harvell, C.D. Climate change and infectious diseases: from evidence to a predictive framework. *Science* **341**(6145), 514-519 (2013).
99. Paz, S. *et al*. Permissive summer temperatures of the 2010 European West Nile Fever upsurge. *PLoS ONE* **8**(2), e56398 (2013).

100. Negev, M. *et al*. Impacts of climate change on vector borne diseases in the Mediterranean Basin – Implications for preparedness and adaptation policy. *Int. J. Environm. Res. & Pub. Health* **12**, 6745-6770 (2015).
101. Rohr, J.R. *et al*. Frontiers in climate change–disease research. *Trends Ecol. Evol.* **26**(6), 270-277 (2011).
102. Semenza, J.C. *et al*. Climate change projections of West Nile Virus infections in Europe: Implications for blood safety practices. *Environm. Health* **15**(Suppl 1):28, 125-136 (2016).
103. ECDC (European Centre for disease Prevention and Control), The climatic suitability for dengue transmission in continental Europe. Stockholm, Sweden. (2012), Available online: http://ecdc.europa.eu/en/publications/Publications/TER-Climatic-suitablility-dengue.pdf
104. ECDC (European Centre for disease Prevention and Control), Annual Epidemiological Report 2016: Dengue fever. Stockholm, Sweden. (2016), Available online: http://ecdc.europa.eu/en/healthtopics/dengue_fever/Pages/Annual-epidemiological-report-2016.aspx
105. Adger, W.N. *et al*. Human security. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B. *et al*. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 755-791. (2014).
106. Hallegatte, S. An exploration of the link between development, economic growth, and natural risk. World Development Report Background Paper, World Bank, (2014).
107. Becker, A., Inoue, S., Fischer, M. & Schwegler, B. Climate change impacts on international seaports: knowledge, perceptions, and planning efforts among port administrators. *Clim. Change* **110**(1), 5-29 (2012).
108. Sanchez-Arcilla, A. *et al*. A review of potential physical impacts on harbours in the Mediterranean Sea under climate change. *Reg Env. Change* **16**(8), 2471–2484 (2016).
109. Sierra, J.P., Casanovas, I., Mösso, C., Mestres, M. & Sanchez-Arcilla, A. Vulnerability of Catalan (NW Mediterranean) ports to wave overtopping due to different scenarios of sea level rise. *Reg. Env. Change* **16**, 1457-1468 (2016).
110. Nicholls, R.J. *et al*. Ranking port cities with high exposure and vulnerability to climate extremes: Exposure estimates. OECD Environment Working Papers No. 1, OECD Publishing, (2008).
111. Hallegatte, S., Green, C., Nicholls, R.J. & Corfee-Morlot, J. Future flood losses in major coastal cities. *Nature Clim. Change* **3**, 802–806 (2013).
112. Satta, A., Puddu, M., Venturini, S. & Giupponi, C. Assessment of coastal risks to climate change related impacts at the regional scale: The case of the Mediterranean region. *Int. J. Disaster Risk Reduct.* **24**, 284-296 (2017).
113. Ciscar, J.C. *et al*. Climate Impacts in Europe. The JRC PESETA II Project. JRC Scientific and Policy Reports, EUR 26586EN, (2014), available at https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/climate-impacts-europe-jrc-peseta-ii-project
114. Tolba, M.K. & Saab, N.W. Impact of climate change on Arab countries. Report of the Arab Forum for Environment and Development (AFED), Beirut, Lebanon. 159pp (2009).
115. Hegazi, A.M., Afifi, M.Y., Elwan, A.A., Shorbagy, M.A.E.L. & El-Demerdashe, S. (eds.) Egyptian National Action Program to Combat Desertification. Desert Research Center, Ministry of Agriculture and Land Reclamation, Cairo, 128 pp, (2005), available at http://www.unccd.int/ActionProgrammes/egypt-eng2005.pdf
116. Rubio, J.L., Safriel, U., Daussa, R., Blum, W. & Pedrazzini, F. Water scarcity, land degradation and desertification in the Mediterranean region. NATO Science for Peace and Security Series C: Environmental Security, Springer Science + Business Media B.V. (2009).
117. Arab Center for the Studies of Arid zones and Dry lands (ACSAD), Regional Report on Desertification in the Arab World, Damascus, Syria (2000).
118. Renaud, F., Dun, O., Warner, K. & Bogardi, J. A decision framework for environmentally induced migration. *Int. Migrat.* **49**(S1), e5-e29 (2011).

119. Gleick, P.H. Water, drought, climate change, and conflict in Syria. *Weather Clim. Soc.* **6**, 331-340 (2014).
120. Warner, K. *et al*. Human security, climate change, and environmentally induced migration. In: T. Dokos (ed.) *Climate Change: Addressing the Impact on Human Security*. 46-67. UNU-EHS Reports. (2013).
121. Wodon, Q., Liverani, A., Joseph, G. & Bougnoux, N. (eds.) Climate Change and Migration: Evidence from the Middle East and North Africa. World Bank Studies. Washington, DC: World Bank. (2014).
122. Brzoska, M. & Fröhlich, C. Climate change, migration and violent conflict: vulnerabilities, pathways and adaptation strategies, *Migrat. Developm.* **5**, 190-210 (2016).
123. Oppenheimer, M. *et al*. Emergent risks and key vulnerabilities. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B. *et al*. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1039-1099. (2014).
124. Steffen, W. *et al*. Planetary boundaries: Guiding human development on a changing planet, *Science* **347**, 6223 (2015).
125. Plan Bleu, Economic and social analysis of the uses of the coastal and marine waters in the Mediterranean, characterization and impacts of the fisheries, aquaculture, tourism and recreational activities, maritime transport and offshore extraction of oil and gas sectors. 134 p. Valbonne: Plan Bleu (2014)
126. MEDSEC Environment and Security Issues in the Southern Mediterranean Region, Geneva, Zoï Environment Network, (2009); available at http://www.grida.no/publications/security/book/3951.aspx

Acknowledgements

This paper has benefited from discussions with V. Alary (CIRAD, Montpellier, France), W.W.L. Cheung (Univ. British Columbia, Vancouver, Canada), K. Radunsky (Umweltbundesamt, Vienna, Austria), J. Le Tellier (Plan Bleu, Marseille, France), C. Webster (MedPAN, Marseille, France), and participants at a MedECC workshop, held in Aix-en-Provence, France, in October 2016. Coordination was supported by the Labex OT-Med (project ANR-11-LABEX-0061), funded by the Excellence Initiative of Aix-Marseille University-A*MIDEX, a French “Investissements d’Avenir” French programme.

Author contributions

W.Cr. and J.Gu. developed the assessment protocol and convened the author team; all authors contributed sectoral knowledge and text; W.Cr. wrote the paper.

Competing financial interests

The authors declare no competing financial interests

Figures

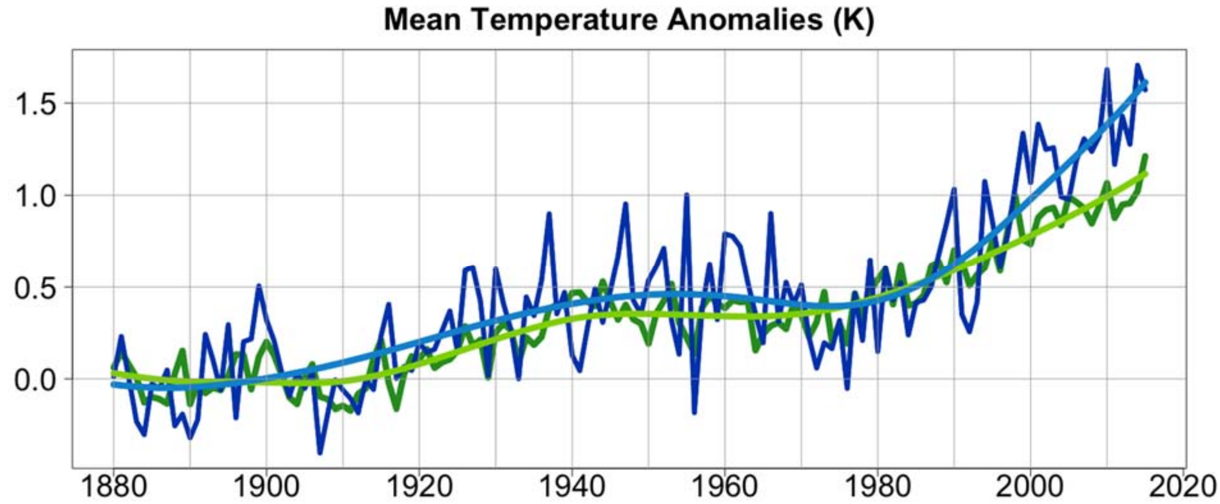

Figure 1 | Historic warming of the atmosphere (annual mean temperature anomalies with respect to the period 1880-1899), in the Mediterranean Basin (blue lines) and for the globe (green lines), with and without smoothing. Data from Berkeley Earth available at http://berkeleyearth.org/

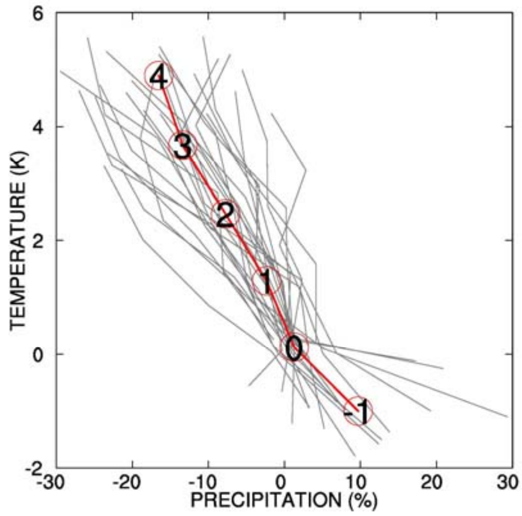

Figure 2 | Trajectory (red line) describing the ensemble mean evolution of the climate of the Mediterranean region towards warmer and drier conditions as function of global mean temperature change (°C). Results are based on an ensemble of 28 CMIP5 global simulations, individually shown by the grey lines. All values are anomalies with respect to the corresponding 1971-2000 mean (redrawn from ref *15*)

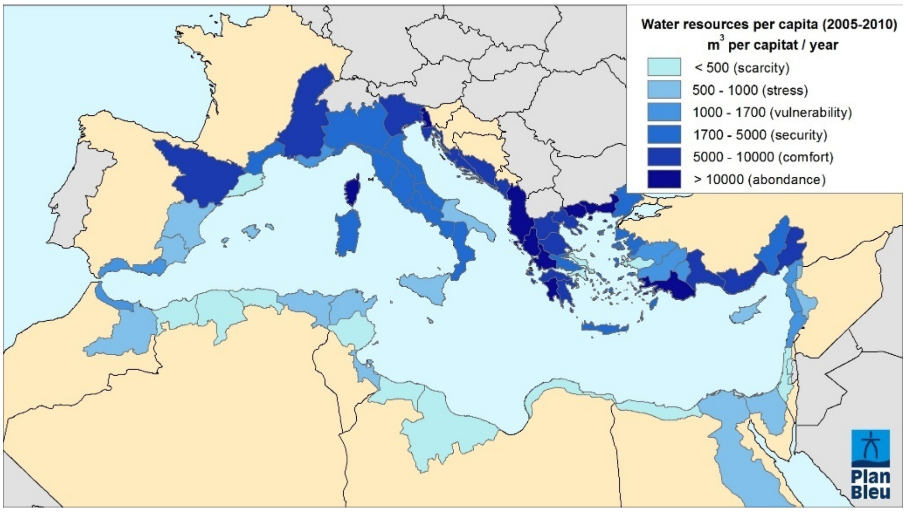

Figure 3 | Annual natural renewable water resources per capita in the Main Mediterranean watersheds, expressed as levels of shortage for human use (from ref *125*)

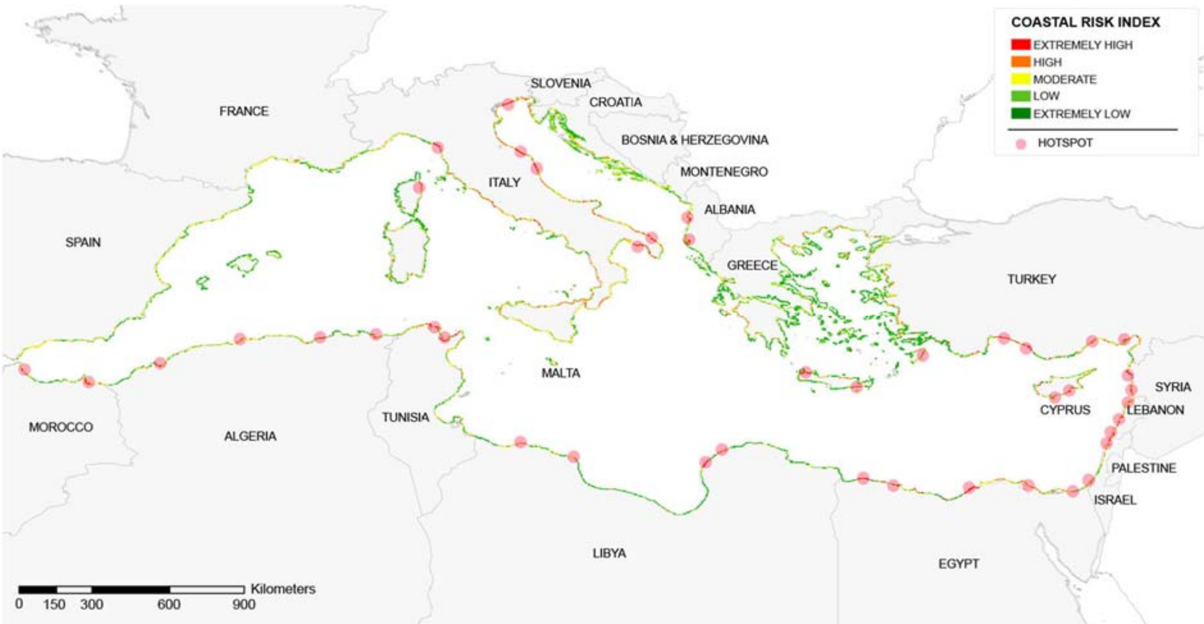

Figure 4 | Coastal risks in the Mediterranean countries (from ref *112*)

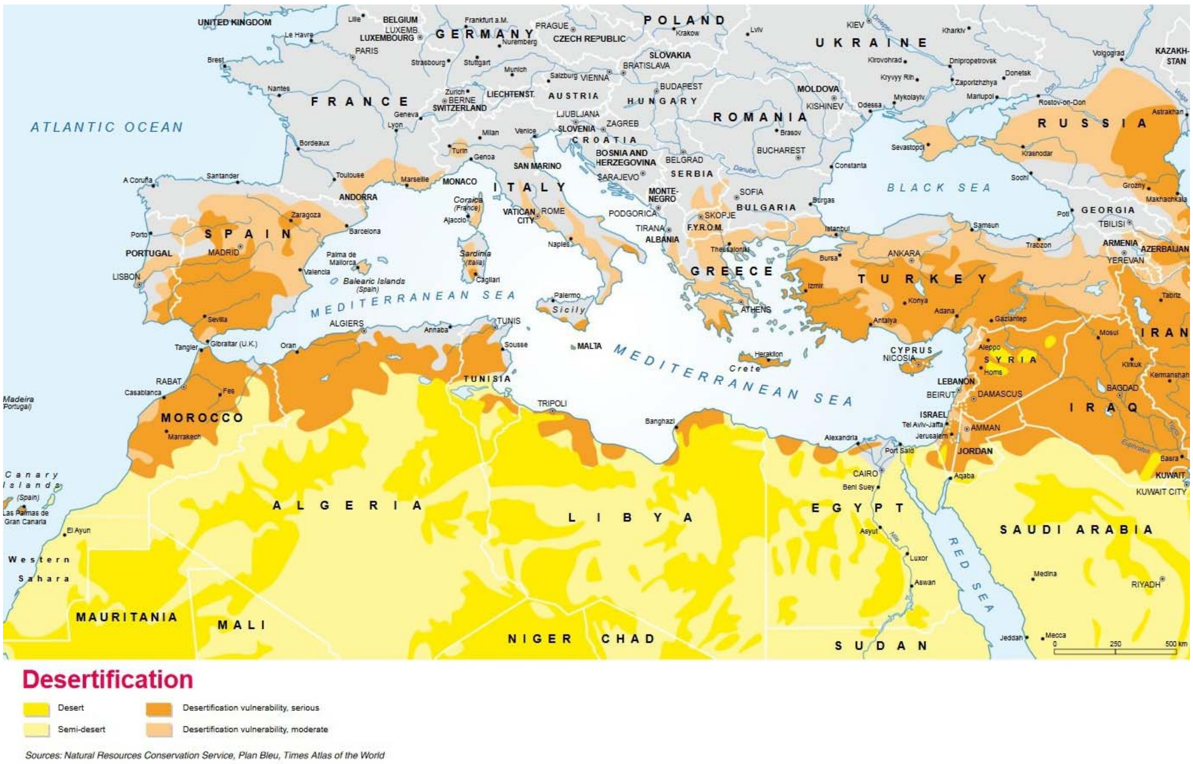

Figure 5 | Desertification trends around the Mediterranean (from ref *126*)